PRETTY PRAIRIE NITRATE STUDY

Modeling and Characterization

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1.0 Introduction

The following report presents the results of a study addressing nitrate contamination of the Public Water Supply (PWS) at Pretty Prairie, Kansas. Pretty Prairie is a small community of approximately 600 people that is located in south central Kansas (see Figure 1.1). The community receives its water supply from ground water. In the area, ground water flows to the east and occurs approximately 25 feet below the surface in an aquifer consisting of silt, sand, and gravel deposits of Pleistocene age. The aquifer has a saturated thickness of approximately 50 feet and is underlain by Permian sedimentary rocks, which act as an aquitard. Of concern to the community is that the ground water is contaminated with nitrate. In particular, for at least the past six years the ground-water supply has consistently exceeded the maximum contaminant level (MCL) for nitrate, a value of 10 mg/L.

The purpose of the study is to estimate how ground-water nitrate concentrations would change if no further nitrate is introduced into the aquifer from agricultural activities and to provide insight on the distribution of nitrate in the ground water. Nitrate acts as a conservative chemical species in ground water; it is neither sorbed by aquifer materials nor does it enter into most chemical reactions (Frimpter et al., 1988). The study involved two aspects: (1) modeling simulations and (2) characterization of the local ground-water nitrate concentrations. Data for the study was obtained primarily from USEPA Region 7 and included water quality measurements, maps, and reports.

2.0 Simulation of Nitrate Attenuation

Due to the lack of sufficient hydrogeologic data at the site, a simple mixing model was selected for this study. The mixing model is based on the mass balance principle of ground water and nitrate. It is assumed that no chemical reaction of the nitrate in the subsurface occurs (see the attached derivation for detail) and that the nitrate is completely mixed within the aquifer. Although nitrogen may be introduced to ground water in several dissolved forms, the proposed approach assumes that all nitrogen in ground water is converted to nitrate. The estimated nitrate concentration in the ground water can be expressed as follows:

$$C(t) = C_o \exp\left(-t\frac{Q}{V_a}\right) + \frac{Q_a C_a}{Q}\left[1-\exp\left(-t\frac{Q}{V_a}\right)\right] + \frac{Q_u C_{uo} V_u}{QV_u - Q_u V_a}\left[\exp\left(-t\frac{Q_u}{V_u}\right) - \exp\left(-t\frac{Q}{V_a}\right)\right] \qquad (1)$$

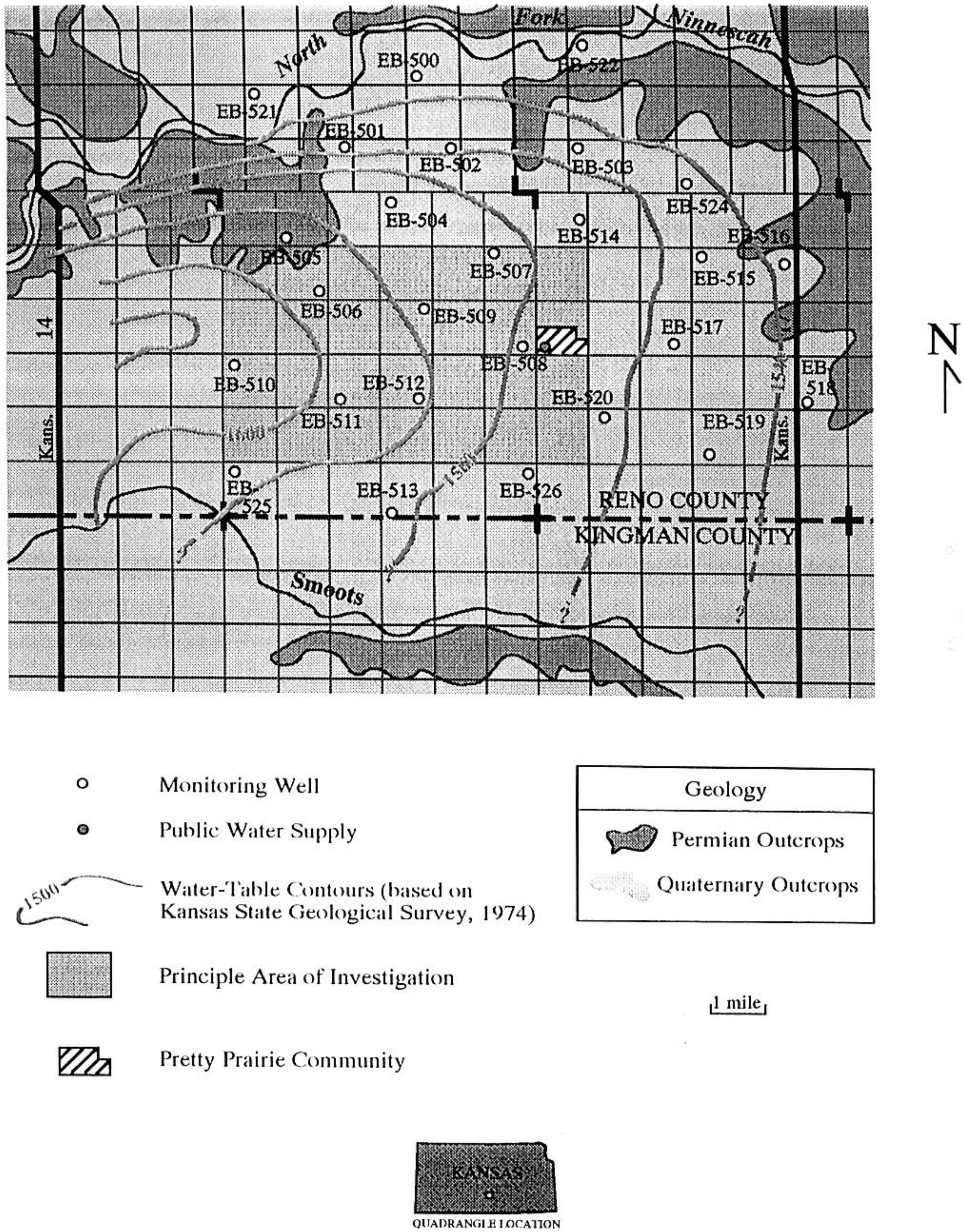


Figure 1.1: Site map of Pretty Prairie, Kansas.

where:

$C(t)$: Nitrate concentration at a specified time [Mass/Vol],

C_o: Initial concentration of aquifer [Mass/Vol],

t: Time [Time],

Q: Total flow rate ($=Q_a+Q_u$) [Vol/Time],

Q_a: Horizontal groundwater inflow rate [Vol/Time],

V_a: Saturated modeling volume (area x saturated thickness x porosity) [Vol],

Q_u: Vertical inflow rate through unsaturated zone [Vol/Time],

C_a: Concentration of horizontal inflow water [Mass/Vol],

C_{uo}: Initial concentration at the unsaturated zone [Mass/Vol],

V_u: Unsaturated modeling volume (area x unsaturated thickness x volumetric water content), [Vol].

The input parameter values for the model were derived primarily from existing reports describing the hydrologic, geologic and pedologic conditions within the area (see Table 2.1). Based on cross sections and potentiometric surface information in the study area (Kansas Geological Survey, 1978; State Geological Survey of Kansas, 1956) the aquifer is assumed to represent a rectangular-shaped box having a length of 7 miles (the direction of ground-water flow), a width of 4 miles, and a thickness of 30 feet. The nitrate concentration values of C_o, C_a, C_{uo} were assumed to equal 20 mg/L. This value is conservative and is based on the highest range of the field measured nitrate concentrations (USEPA, 1994). Considering the topography, vegetation, and soil type at the site, it was assumed that 20 percent of the annual average precipitation infiltrates into the aquifer from the upper surface of the model area. The average annual precipitation, 28.61 inches, was obtained from a 30 year compilation taken at Wichita, Kansas (van der Leeden et al., 1990). A uniform hydraulic gradient was estimated as 0.0021 ft/ft from the regional potentiometric map (Kansas Geological Survey, 1978). The aquifer hydraulic conductivity was assumed as 13.04 feet per day and was based a field measurement taken in a similar geologic setting at the Burrton Site (U.S. Geological Survey, 1987), which is located at about 15 miles northeast of the Pretty Prairie. The modeling area was assumed homogeneous and isotropic.

In the modeling study, three scenarios were simulated for the nitrate attenuation, and the results were given in terms of relative concentration (C/C_o). For all three scenarios, a sensitivity analysis was performed by varying the values of the input parameters to illustrate the change in the rates of attenuation. The values of three selected parameters, the hydraulic conductivity of the aquifer, the saturated aquifer thickness, and the infiltration rate, were varied to represent the possible range of "low" and the "high" values associated with field variability, heterogeneity and uncertainty.

TABLE 2.1 INPUT PARAMETER VALUES USED IN THE MIXING MODEL

Input Parameters	*Value*	*Source**
Length of the model area	7 miles	I, II
Width of the model area	4 miles	I, II
Thickness of the aquifer	30 ft	I, II
Thickness of the unsaturated zone	20 ft	I, II
Porosity of the aquifer (n)	0.30	I, II
Volumetric water content of the unsaturated zone (θ)	0.15	I, II
Hydraulic conductivity of the aquifer (K)	13.04 ft/d	V
Hydraulic gradient (i = dh/dl)	0.0021 ft/ft	II
Horizontal groundwater inflow (Q_a)	17,387 ft^3/d	$Q_a = K*i*Aa$
Vertical infiltration (Ir)	0.0013 ft/d	IV (20% of precipitation)
Vertical inflow rate through the unsaturated zone (Q_u)	1.02E6 ft^3/d	$Q_u = Ir*Au$
Total flow (Q)	1.04E6 ft^3/d	$Q = Q_a+Q_u$
Initial concentration of the aquifer (C_o)	20 mg/L	III
Concentration of horizontal inflow water (C_a)	20 mg/L	III
Initial concentration of the unsaturated zone (C_{uo})	20 mg/L	III

* I : Kansas Geological Survey, 1978
II : State Geological Survey of Kansas, 1956
III : USEPA, 1994
IV : van der Leeden et al., 1990
V : U.S. Geological Survey, 1987

In the first scenario, zero nitrate concentration was assumed to enter the aquifer from the vadose zone, the upper surface of the model. This scenario represents the "best-case" condition when the soil above the aquifer is completely free of nitrate. The lateral ground-water inflow concentration (flow from the sides of the model) is maintained constant at 20 mg/L throughout the simulation time. As shown in the Figure 2.1, C/C_o at 0.5 ranges from approximately 6 years to 23 years depending upon the rate of infiltration, the thickness of the aquifer, and the hydraulic conductivity in the aquifer. That is, given that the initial concentration of the aquifer is 20 mg/L, a conservative estimate, the groundwater would reach 10 mg/L in that given time range for the specified conditions.

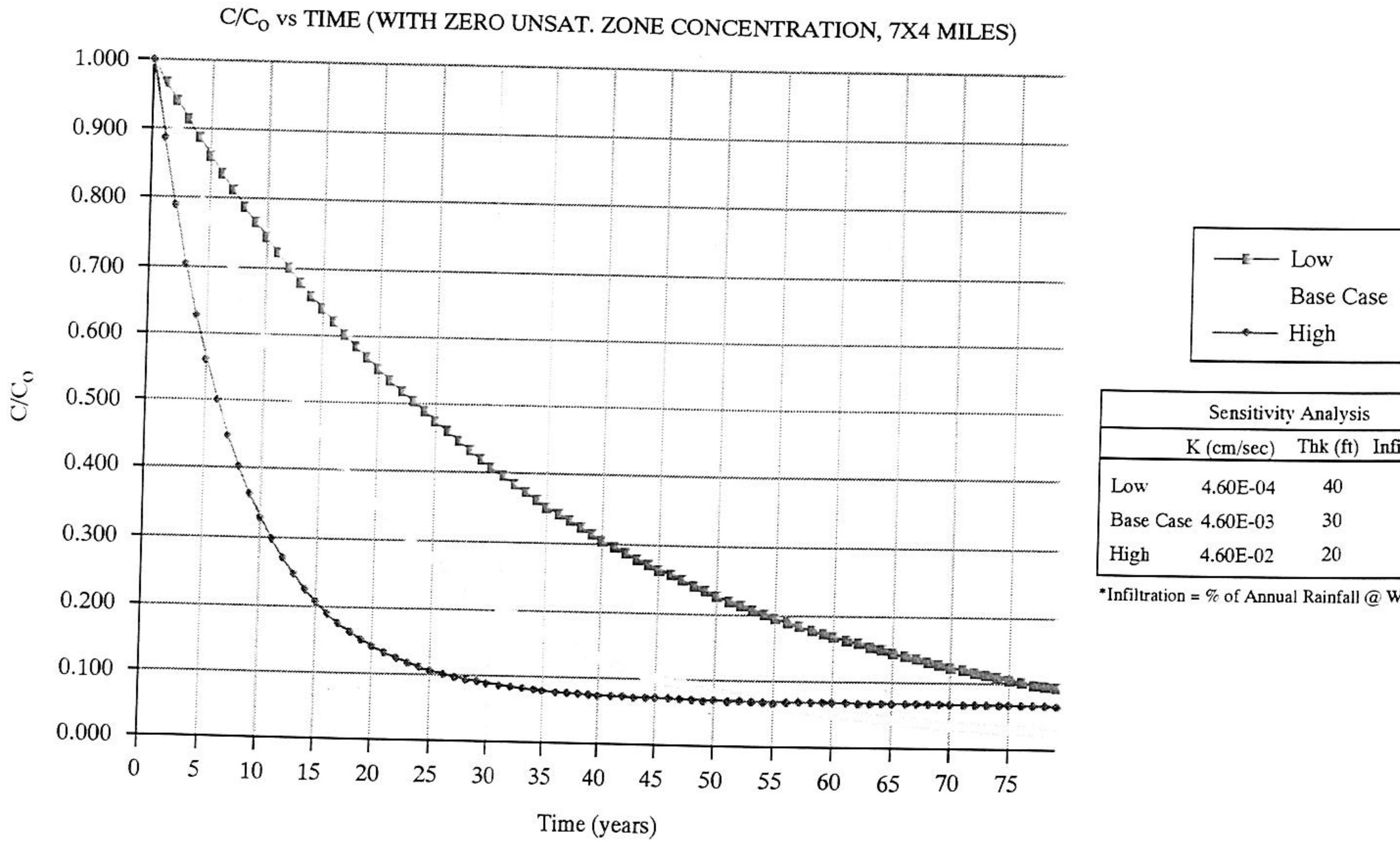
The second scenario is similar to the first scenario except that the initial nitrate concentration entering from the vadose zone is 20 mg/L, and this concentration decreases exponentially with time (see Figure 2.2). This scenario simulates no further addition of nitrogen to the soil; however, residual nitrate in the vadose zone continues to supply nitrate at a reducing rate to the aquifer. Hence, the residual nitrate in the soil is being flushed down to the aquifer even after no further fertilization occurs. The rate of reduction of the inflowing nitrate concentration is illustrated by the curve "C_u/C_{uo},base". In this case, C/C_o at 0.5 ranges from approximately 10 years to 32 years for similar conditions as modeled in the first scenario.

Figure 2.3 depicts the third scenario, which is similar to the second scenario except the size of modeling area is reduced from 7 x 4 miles to 1 x 1 mile. In this case, C/C_o at 0.5 ranges from 13 years to 33 years for the same conditions as modeled in the second scenario. Note that the curve for the "high" values of input parameters becomes horizontal (no further attenuation) after about 25 years. This indicates that after the inflowing nitrate concentration from the vadose zone reaches close to zero, that is, almost all of the nitrate has been flushed out after 25 years, mixing with the lateral inflow (constant concentration of 20 mg/L) becomes constant (C/C_o equals 0.35). The results of the sensitivity analysis for scenario three are similar to those of scenario two.

In summary, the modeling simulations are screening level estimates of nitrate attenuation in the aquifer. The simulation results are based on limited site data as well as the above mentioned assumptions and conceptualization. As shown in Figures 2.1 through 2.3 and Table 2.2, the simulation results indicate that the time required to reduce the initial nitrate concentrations by half (50 percent) varies from 6 to 23 years if the infiltrating ground water is completely clean and from 10 to 33 years if the infiltrating ground water contains residual nitrate. The variability in the estimated time is dependent on the selected input parameters. For a more detailed estimation, ground-water flow and transport simulations could be performed if additional site data become available.

TABLE 2.2 SIMULATED TIME (IN YEARS) REQUIRED FOR THE C/C_o REACHES 0.5

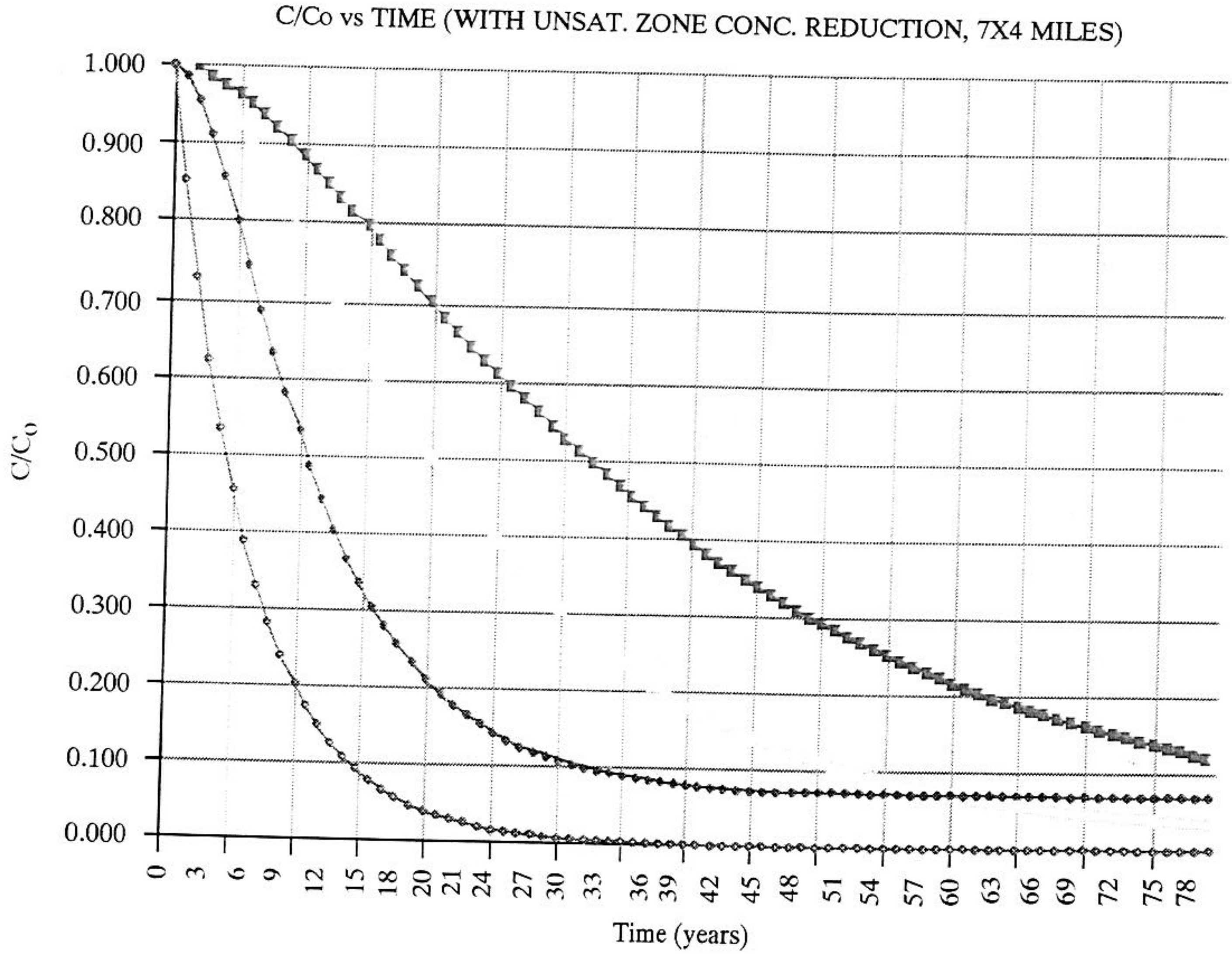
Parameter variation	*Scenario I*	*Scenario II*	*Scenario III*
Low	6	10	13
Base	13	20	21
High	23	32	33



Sensitivity Analysis			
	K (cm/sec)	Thk (ft)	Infiltration*
Low	4.60E-04	40	15%
Base Case	4.60E-03	30	20%
High	4.60E-02	20	30%

*Infiltration = % of Annual Rainfall @ Wichita, KS

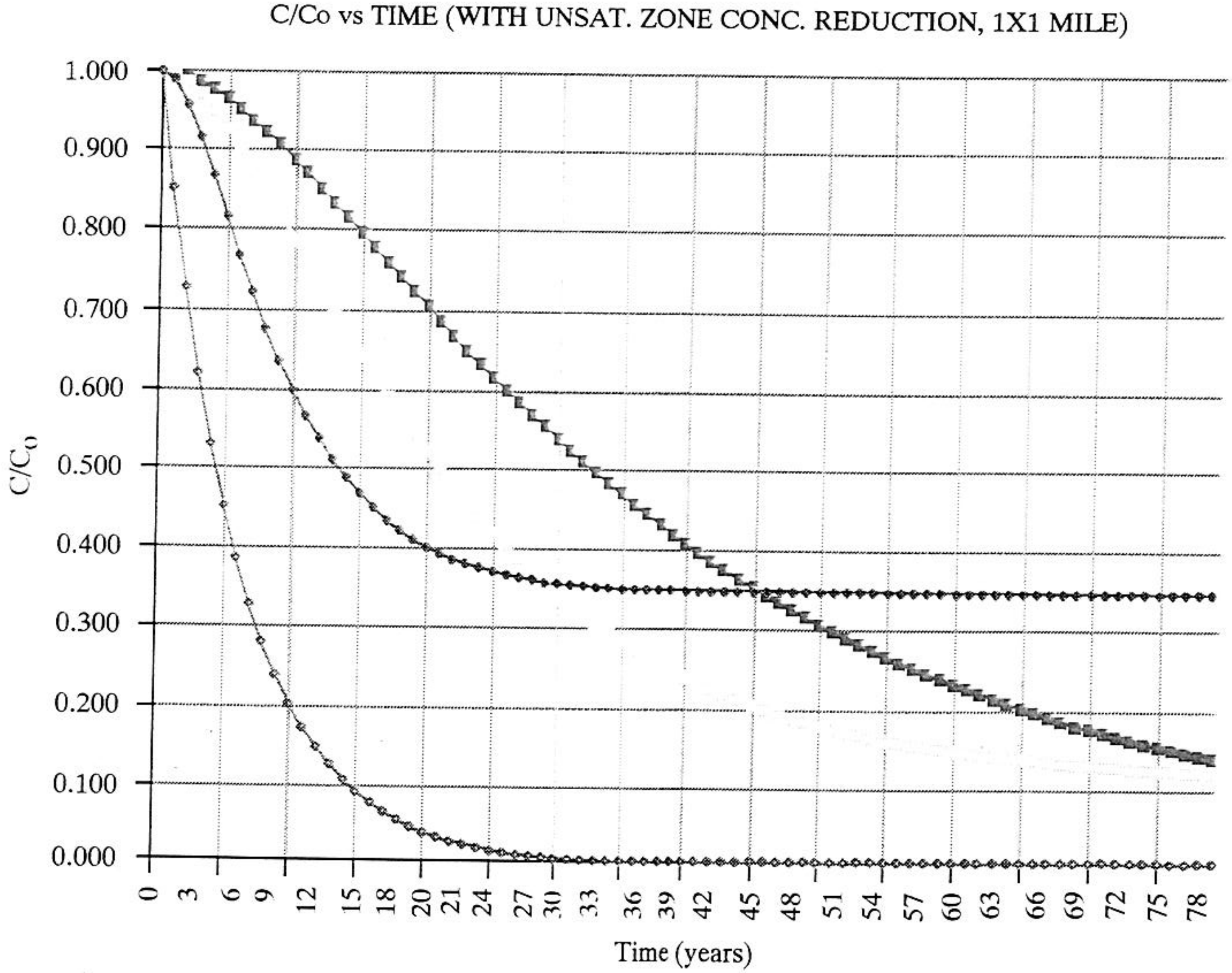
Figure 2.1: Initial modeling scenario with inflow nitrate concentration equal to 0.0.



Sensitivity Analysis			
	K (cm/sec)	Thk (ft)	Infiltration*
Low	4.60E-04	40	15%
Base Case	4.60E-03	30	20%
High	4.60E-02	20	30%

*Infiltration = % of Annual Rainfall @ Wichita, KS

Figure 2.2: Second modeling scenario with decaying nitrate source concentration. Initial nitrate source concentration equals 20.0 mg/L.



Sensitivity Analysis			
	K (cm/sec)	Thk (ft)	Infiltration*
Low	4.60E-04	40	15%
Base Case	4.60E-03	30	20%
High	4.60E-02	20	30%

*Infiltration = % of Annual Rainfall @ Wichita, KS

Figure 2.3: Third modeling scenario with decaying nitrate source concentration. Initial nitrate source concentration equals 20.0 mg/L. The modeling area equals 1 x 1 mile.

3.0 Characterization of Ground-Water Nitrate Concentrations

Characterization of the local ground-water conditions involved investigating the distribution of nitrate within the aquifer. In particular, the study focused on the lateral and temporal distributions of nitrate in the area proximal to the Pretty Prairie, and more specifically, the area upgradient of the Public Water Supply. An investigation of the vertical distribution of nitrate in the aquifer could not be comprehensively conducted since elevations of the top-of-casing for the monitoring wells were not available.

The distribution of nitrate in the aquifer is heterogeneous with concentrations ranging from less than 1.0 mg/L to almost 20 mg/L. For example, within a 3-mile radius of Pretty Prairie the nitrate concentrations ranged from 2.90 mg/L to 19.8 mg/L during December 1993 (USEPA, 1994). The heterogeneous distribution is clearly observable in the surface plot (Figure 3.1) of concentration in the area west of Pretty Prairie, the assumed upgradient direction. It should be recognized that the concentrations observed at the Pretty Prairie PWS and Well 508, which is located about 1/4 mile west of the town, average about 19 mg/L and are the highest in the vicinity. In the area surrounding these locations, the nitrate concentrations generally range between 9 and 12 mg/L. This distribution suggests that additional nitrate sources probably exist in close proximity to the PWS.

To assess temporal trends, nitrate concentrations were studied from monthly measurements taken over a 2-year period at monitoring wells within the area as well as quarterly measurements taken over a 6 year period at the PWS. As illustrated in Figure 3.2 the nitrate concentrations for a given well and depth typically vary less than $\pm$ 2.0 mg/L. In addition, most wells indicate an increase in nitrate concentration in the month of June; the reason for this rise is uncertain but is probably related to agricultural activities within the area. Further, nitrate concentrations generally increased in the late spring of 1993 (April, May, June); this trend is probably due to the abnormally high precipitation that occurred during this time period. The results of this analysis indicate that nitrate concentrations at a given location and depth are relatively constant through time. Figure 3.3, which illustrates the nitrate concentrations recorded at the Pretty Prairie PWS, shows a slight decreasing trend in concentration during the past six years as well as a trend toward relatively constant nitrate concentrations. Since nitrate can be assumed to be a conservative contaminant that neither sorbs nor decays in the aquifer, the consistency of the nitrate concentrations in both the monitoring wells and the PWS suggests constant sources of nitrate and relatively steady-state ground-water flow conditions.

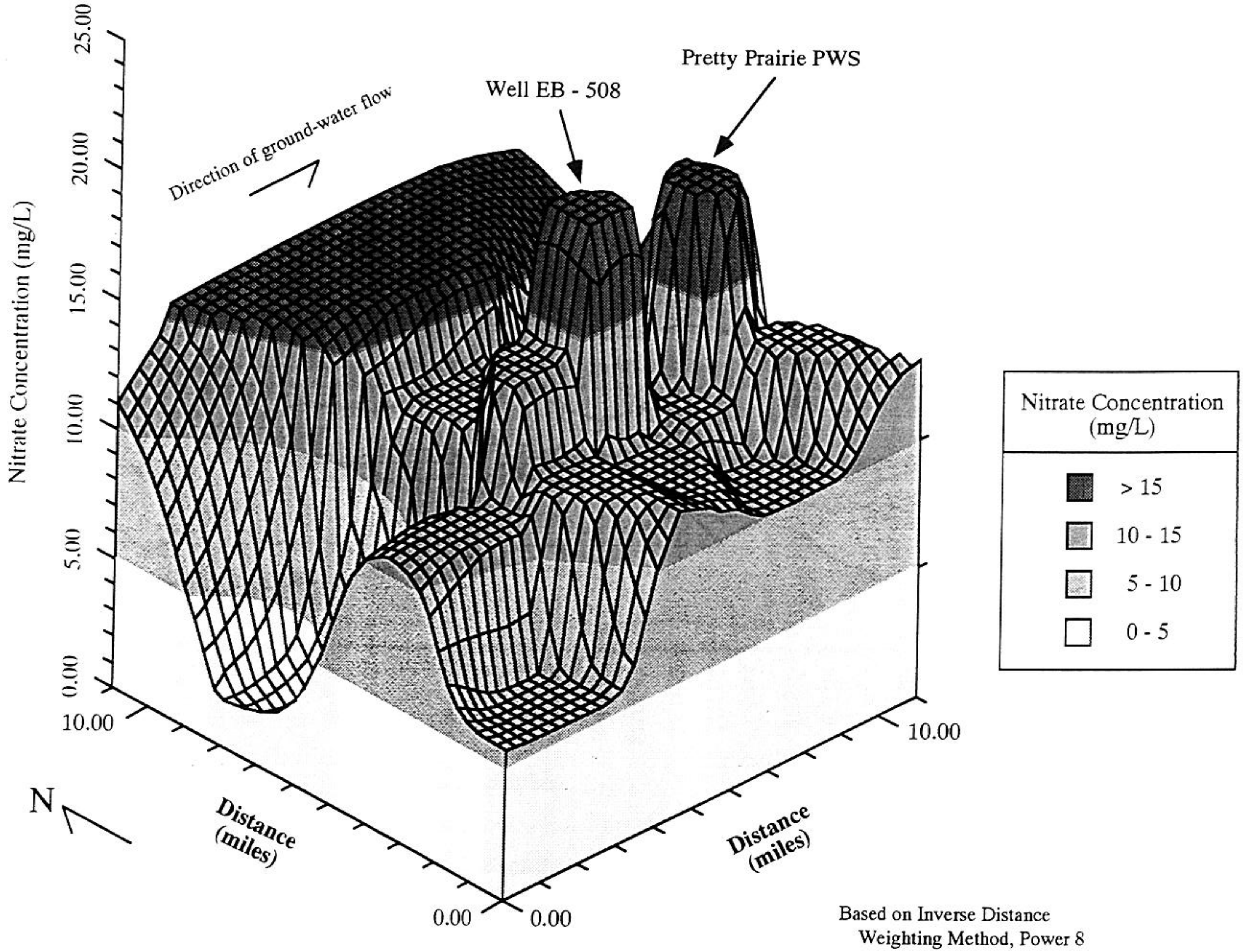


Figure 3.1: Surface plot of measured nitrate concentrations in the vicinity of Pretty Prairie.

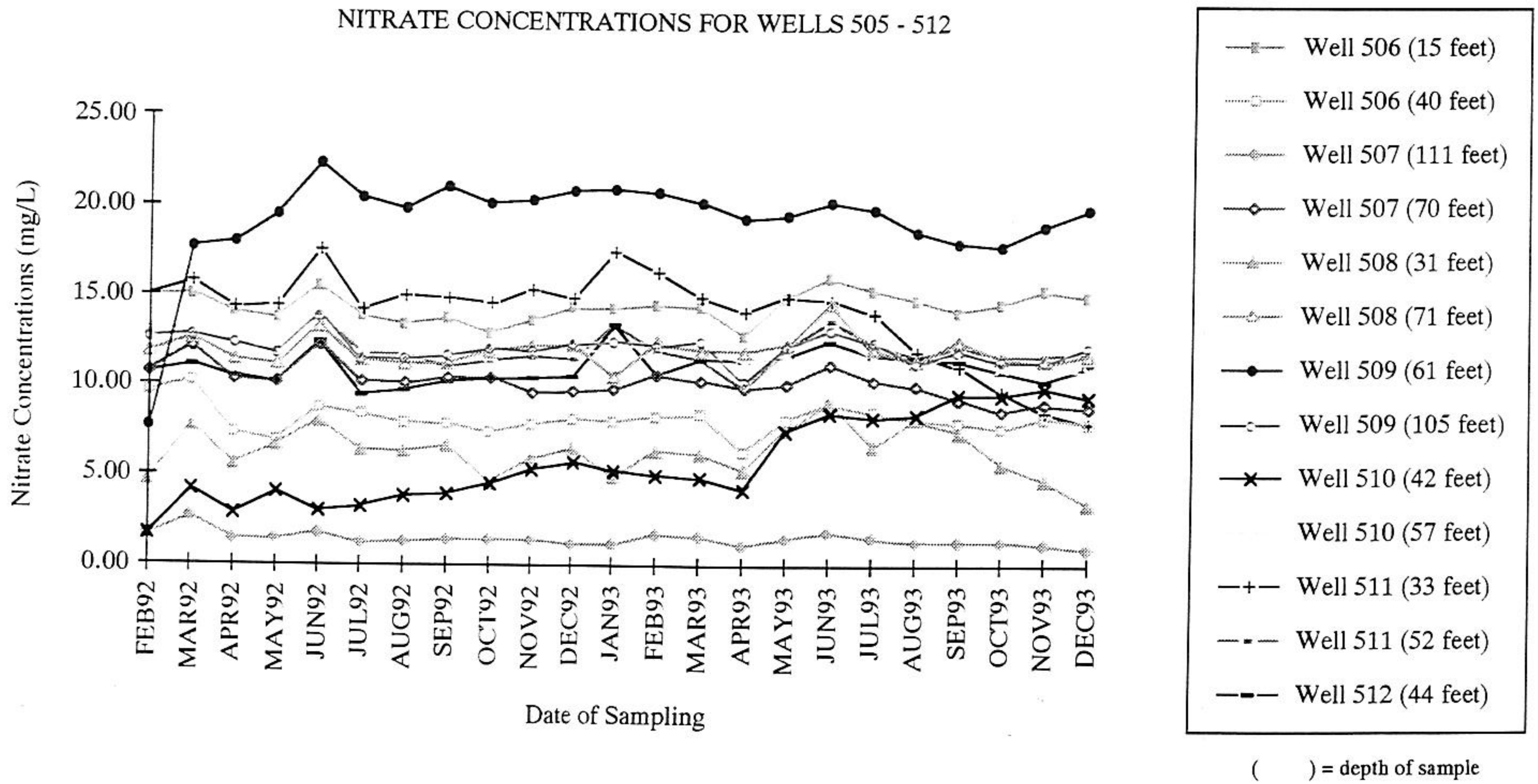


Figure 3.2: Nitrate concentrations through time of selected wells in the vicinity of Pretty Prairie PWS.

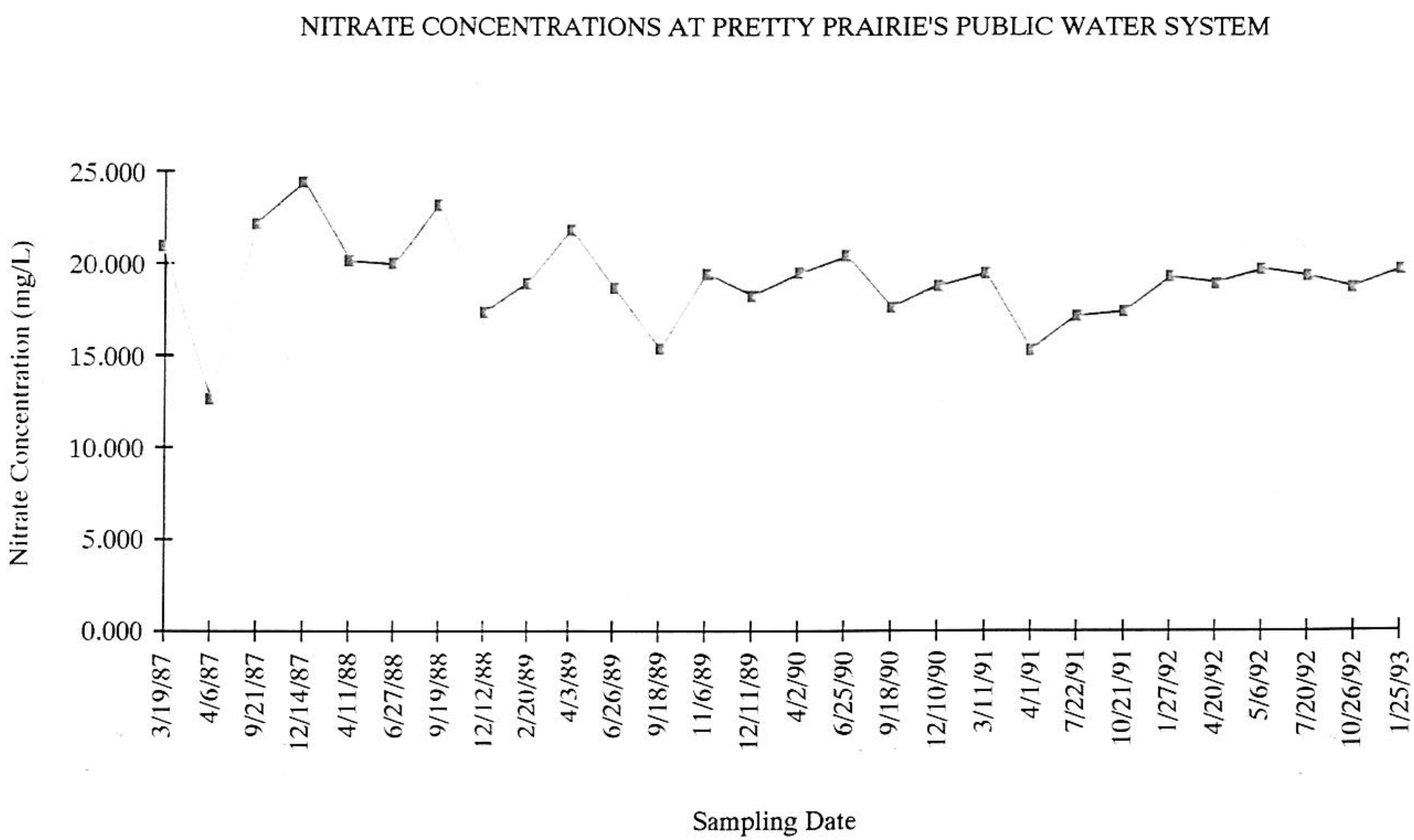


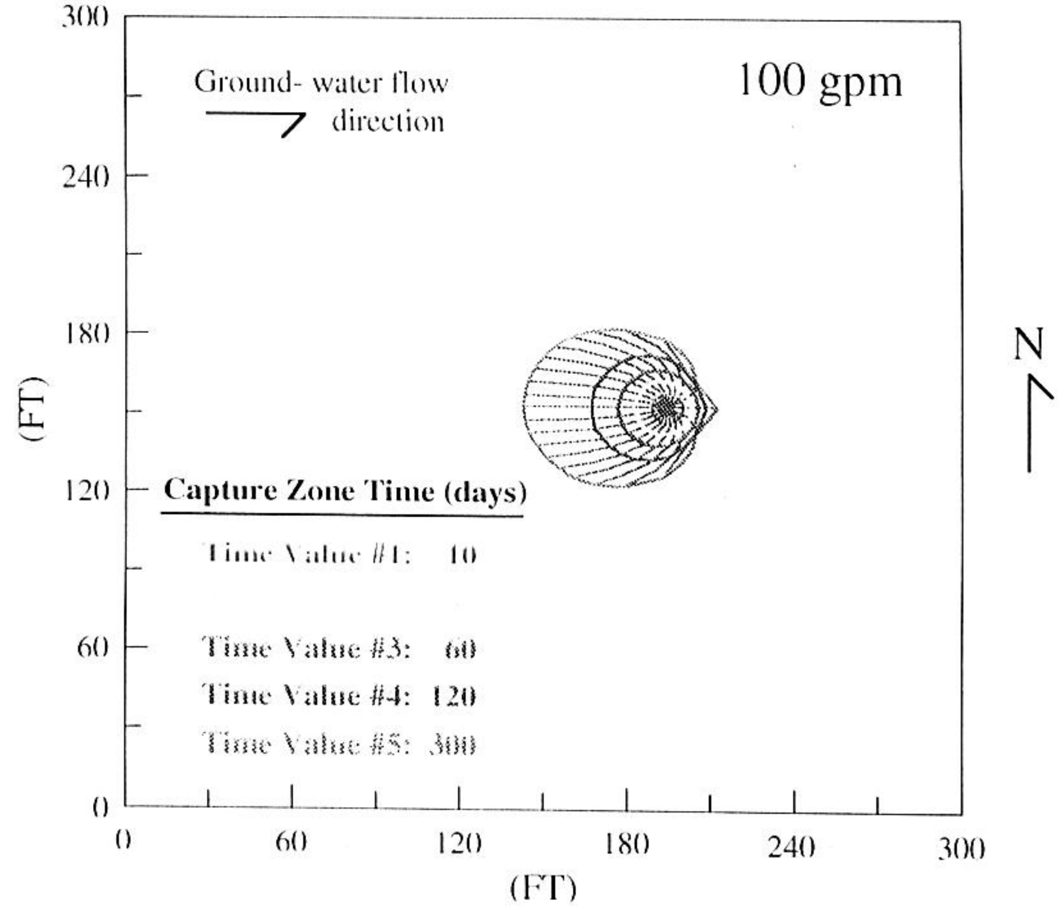
Figure 3.3: Measured nitrate concentrations from March 1987 through January 1993.

The final aspect of the characterization study involved assessing the capture zone area for the PWS. This was conducted using RESSQC, version 2.2 (Blandford and Huyakorn, 1991), which is a module within the model WHPA, a public domain code developed by the USEPA. RESSQC is a two-dimensional semi-analytical code that delineates time-related capture zones around pumping wells. The code assumes a homogeneous, isotropic aquifer of infinite areal extent having steady and uniform ambient ground-water flow. Input parameters for the modeling were based on the base case conditions described in Section 2 of this report and are given below.

Aquifer Thickness = 30 feet
Hydraulic Conductivity = 0.0046 cm/sec (= 13.04 feet/day)
Aquifer Transmissivity = 391 feet^2/day
Porosity = 0.3
Hydraulic Gradient = 0.0021 (west to east)
Pumping Rate = 100/300 gpm (gallons per minute)

Results of the capture zone modeling are presented in Figure 3.4. The modeling results indicate that over a time interval of 300 days the capture zone area is less than 13,000 square feet for continuous pumping at 300 gpm. Information received from USEPA Region 7 indicates that the PWS pumps intermittently, which would produce a smaller capture zone area. Due to the uncertainty associated with the pumping schedule several time intervals were simulated and a lower pumping rate, 100 gpm, was also modeled. The results of the modeling indicate that the capture zone area is relatively small and extends westward from the well location.

Characterization of the nitrate contamination in the aquifer indicates three general patterns: (1) nitrate concentrations are heterogeneously distributed in the aquifer, (2) nitrate concentrations at a given location are relatively constant through time, and (3) the nitrate concentrations proximal to the Pretty Prairie PWS are higher than the surrounding area. Further, modeling of the PWS capture zone indicates the area that provides water to the well is relatively small, less than 0.01 square mile. From these facts, it appears that two general nitrate sources contribute to the contamination exhibited at the Pretty Prairie PWS: (1) a local source, and (2) a regional source.



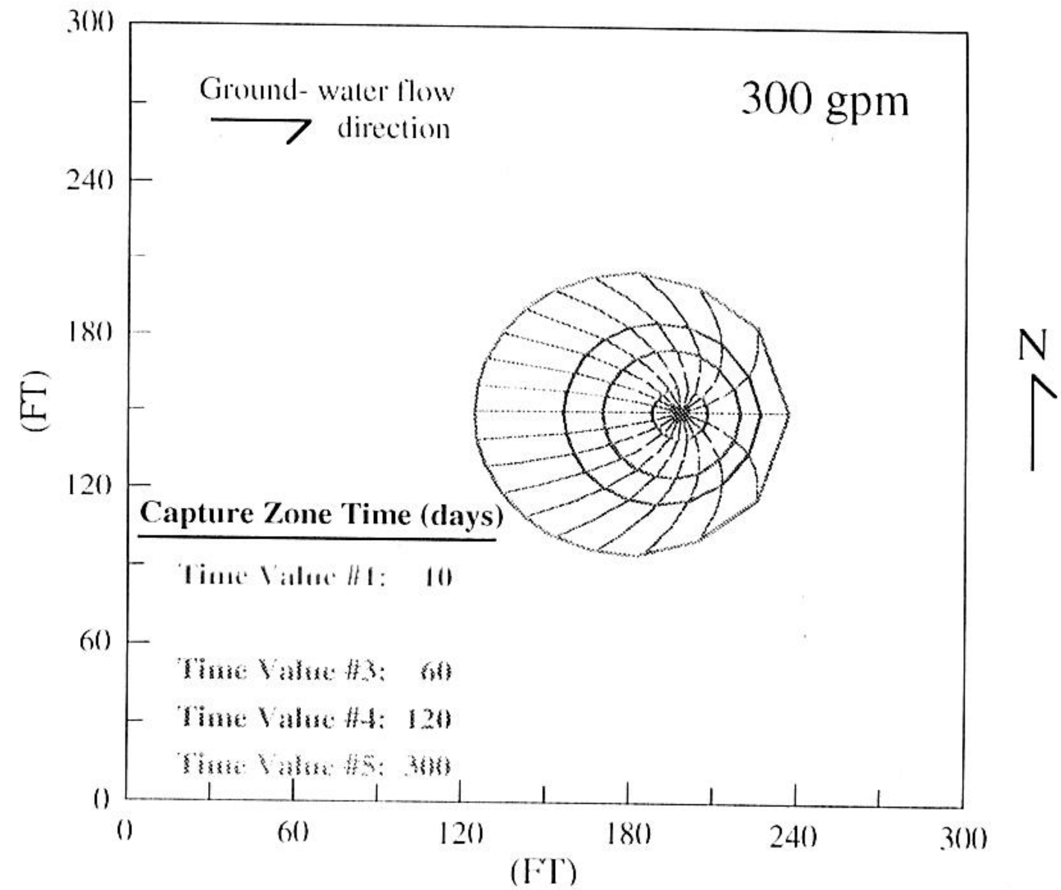


Figure 3.4: Simulated capture zones for Pretty Prairie PWS using base case conditions.

4.0 Discussion

Calculations were conducted to ascertain the influence and potential interrelationship between the regional and local nitrate sources on the PWS. Specifically, the calculations involved estimating what portion of the pumped ground water is obtained from a local high nitrate source(s) and what sources could produce the nitrate concentrations. For example, given a background nitrate concentration of 10 mg/L, the approximate regional nitrate concentration in the aquifer, what percent of the ground-water flow derived from a higher nitrate source would produce a concentration of 19-20 mg/L at the PWS? This question can be determined using the following equation:

$$C = (R \times C_1) + (L \times C_2)$$

where C is the concentration pumped at the well, R is the percentage of regional (background) ground-water flow contributing to the well discharge, L is the percentage of local (high nitrate source) ground-water flow contributing to the well discharge, C_1 is the concentration of the regional ground-water flow (assumed to be 10 mg/L), and C_2 is the concentration of the local ground-water flow. Figure 4.1 illustrates the results of this calculation. In the calculation, the high nitrate local source was varied from 30 mg/L to 60 mg/L based on reported nitrate effluent concentrations from septic systems (Kaplan, 1987). Results of the calculations indicate that approximately 20 percent of the water at the well must be derived from a local nitrate source of 60 mg/L to obtain a pumped concentration of 20 mg/L nitrate at the PWS. If the high nitrate source is 40 mg/L then approximately one-third of the ground-water pumped must be derived from the local source. Clearly, a significant local nitrate source must be contributing contamination to the PWS.

To ascertain a better understanding of the possible local nitrate source(s) calculations were conducted regarding residential sewage, a common nitrate contaminant source. Assuming an average per capita discharge of sewage ranges between 55 and 64 gallons per day (USEPA, 1980 and Ingham, 1980) and assuming a population of 600 for the town of Pretty Prairie, then approximately 36,000 gallons of residential sewage effluent is potentially discharged to the ground water per day. This volume is approximately 8 percent of the total PWS well discharge if the PWS well is pumped continuously at 300 gpm for 24 hours and is approximately 25 percent of the total PWS well discharge if the PWS well is pumped for only 8 hours per day. Since the town water supply needs are approximately equal or slightly greater than the volume of sewage effluent, a pumping rate of only 8 hours per day seems more reasonable as this would provide approximately 4 times the required water supply volume (144,000 gallons). Assuming that all the sewage discharge is recirculated back to the well, the nitrate concentration in the sewage effluent would have to be approximately 50 mg/L,

CHANGES IN NITRATE CONCENTRATION WITH RESPECT TO PERCENT FLOW OBTAINED FROM POSSIBLE HIGH NITRATE SOURCE

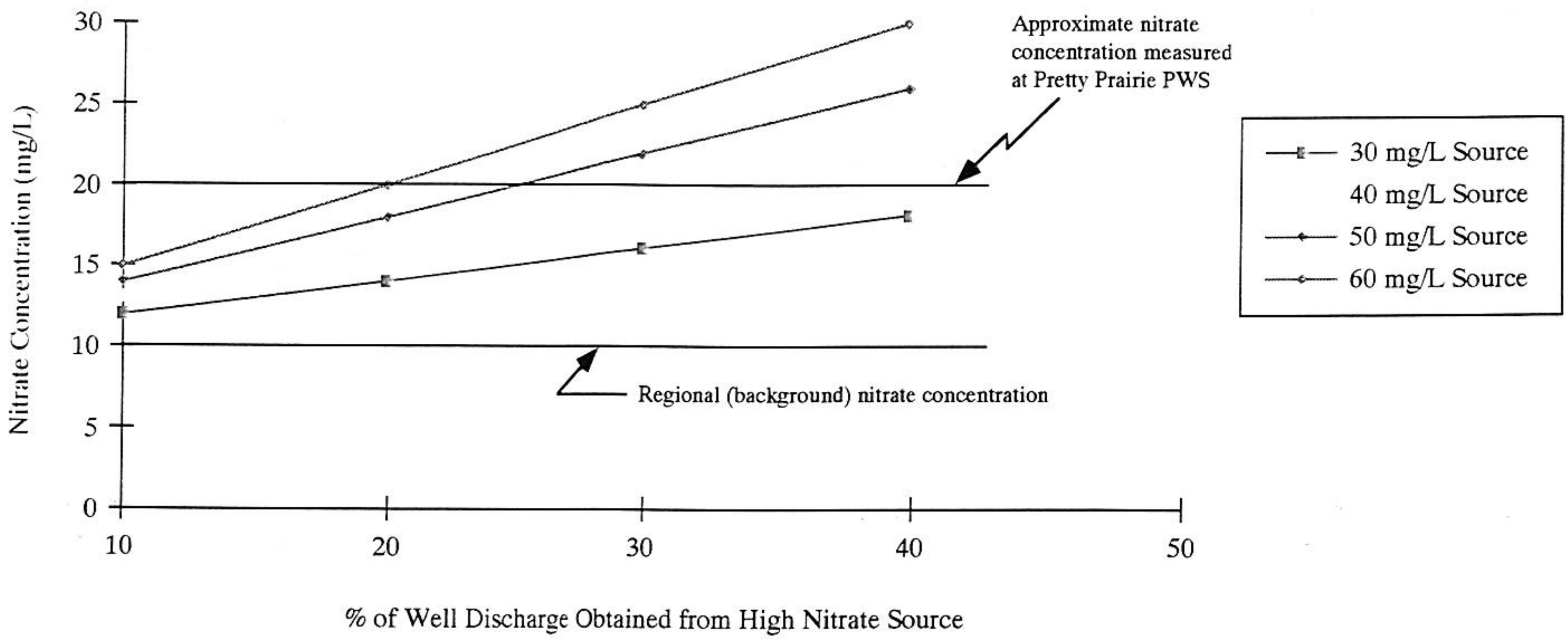


Figure 4.1: Graph illustrating what proportion of high local nitrate flow must be captured by the PWS to obtain a concentration of 20 mg/L from a 10 mg/L background source.

which is a reasonable effluent concentration value (see Figure 4.1). However, if the effluent contributes greater than 25 percent of the flow, then a smaller effluent nitrate concentration would produce a similar result. Conversely, if the volume of sewage effluent is actually lower (the percentage of effluent captured by the well is lower), then two possibilities develop: (1) the nitrate concentration in the effluent is significantly higher than 50 mg/L, and/or (2) additional local sources of nitrate exist in addition to residential wastes.

Finally, when these calculations are related to the original modeling effort that estimated the time of aquifer restoration it can be determined that the regional background nitrate levels will have to be reduced to approximately 5 mg/L to obtain less than MCL nitrate concentrations (see Figure 4.1). Assuming that the current background concentration is 10 mg/L this would take between 10 and 20 years under base case conditions and longer if the average background concentrations are higher. However, if the local sources of nitrate are identified and controlled so that no additional nitrate is introduced, then only a slight reduction of the background nitrate concentrations would be needed for compliance. In this case, the estimated time to reach compliance might be less than the previous base case estimates.

5.0 Conclusions

A study addressing nitrate contamination of the Public Water Supply (PWS) at Pretty Prairie, Kansas was conducted to estimate how ground-water nitrate concentrations would change if no further nitrate was introduced into the aquifer from agricultural activities and to provide insight on the distribution of nitrate in the ground water. The study involved two aspects: (1) modeling simulations and (2) characterization of the local ground-water nitrate concentrations. Data for the study was obtained primarily from USEPA Region 7 and included water quality measurements, maps, and reports.

Due to the lack of sufficient data regarding the flow conditions at the site, a mixing model was selected for the study. The results of the modeling simulations indicate that under average conditions the nitrate concentrations would be reduced by 50 percent in 13 years given that no further nitrate would enter the aquifer from water infiltrating from the vadose zone. Under potentially "best-case" conditions this time interval might be reduced to six years whereas under "worst-case" conditions the time interval might be increased to 23 years. However, given that residual nitrogen probably exists in the soil it will take time to flush this nitrogen from the soil; hence, the residual nitrate will enter the aquifer after fertilization ceases. In this case, the time interval to reduce the nitrate concentrations by 50 percent would be approximately 20 years under base case conditions. Under "best-" and "worst-case" conditions the time interval to reduce nitrate concentrations by half would range between 10 and 33 years.

Characterization of the nitrate contamination in the aquifer indicates three general patterns: (1) nitrate concentrations are heterogeneously distributed in the aquifer, (2) nitrate concentrations at a given location are relatively constant through time, and (3) the nitrate concentrations proximal to the Pretty Prairie PWS are higher than the surrounding area. Further, modeling of the PWS capture zone indicates the area that provides water to the well is relatively small. Based on these factors it appears that local sources as well as regional nitrate sources contribute to the contamination exhibited at the Pretty Prairie PWS.

Assimilating the results of these two phases of the study indicates that to restore the ground water at the Pretty Prairie PWS to below MCL concentrations within a reasonable length of time will require that both regional and local nitrate sources be reduced. In particular, local and regional nitrate sources appear to contribute equally to the contaminant mass at the PWS well. Therefore, the removal of only one source will reduce the nitrate concentration by only 50 percent; since the concentration at the PWS is about 20 mg/L, this will result in a nitrate concentration of approximately 10 mg/L, which is still within unacceptable regulatory limits. Hence, to lower the nitrate concentrations to below the MCL both regional and local nitrate sources will need to be reduced.

In conclusion, the results of this study indicate that greater understanding is needed regarding the potential nitrate sources near the well as well as the flow conditions proximal to the Pretty Prairie PWS. It is recommended that site characterization activities focusing directly on these issues be conducted at the Pretty Prairie PWS. The results of the characterization will reduce the uncertainty associated with the local nitrate contamination and serve as a basis for the design of an effective remedial program.

6.0 References

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APPENDIX A

Model Derivation

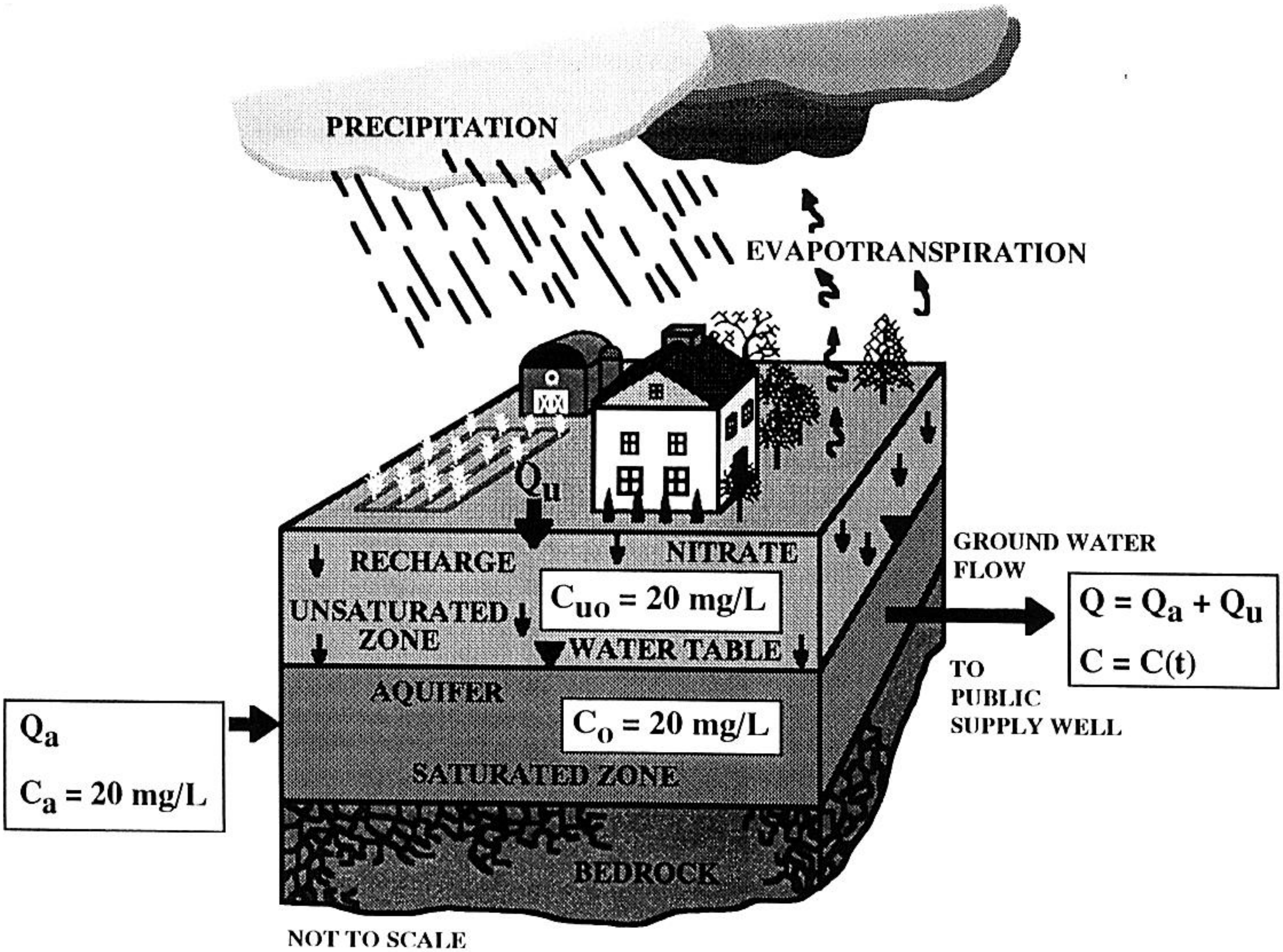

Figure A.1: Definition sketch for the modeling volume for nitrate transport through unsaturated zone and saturated zone

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Assuming that the nitrate entering the modeling volume is uniformly and instantaneously dispersed throughout the volume, one can apply the mass balance principle as follows:

Rate of change of nitrate mass = inflow of nitrate - outflow of nitrate ± $\cancel{\text{generation/decay}}^{\,0}$ (A.1).

Using Figure A.1 and mathematical expression, equation (A.1) can be rewritten

$$\frac{dC}{dt} V_a = Q_a C_a + Q_u C_u - QC \qquad \text{(A.2)}$$

where,

C:	Nitrate concentration at a specified time [Mass/Vol],
t:	Time [Time],
V_a:	Saturated modeling volume [Vol],
Q:	Total flow rate ($=Q_a + Q_u$) [Vol/Time],
Q_a:	Horizontal groundwater inflow rate [Vol/Time],
Q_u:	Vertical flow rate through unsaturated zone [Vol/Time],
C_a:	Concentration of horizontal inflow water [Mass/Vol],
C_u:	Unsaturated concentration at a specified time [Mass/Vol].

The solution for residual nitrate flushing through unsaturated zone due to infiltration can be calculated as below:

$$C_u = C_{uo} \bullet \exp\left(-t\frac{Q_u}{V_u}\right) \qquad (A.3)$$

where,

C_{uo}: Initial concentration at the unsaturated zone [Mass/Vol],

V_u: Unsaturated modeling volume [Vol].

Equation (A.2) can be rewritten by substituting equation (A.3):

$$\frac{dC}{dt}V_a + QC = Q_aV_a + Q_uC_{uo}\exp\left(-t\frac{Q_u}{V_u}\right) \qquad (A.4)$$

Using the Laplace Transform (Wylie, C.R., and L.C. Barrett, 1982) and the initial condition, $C(t=0) = C_o$, the solution to the above equation (A.4) can be found:

$$C(t) = C_oe^{-t\left(\frac{Q}{V_a}\right)} + \frac{Q_aC_a}{Q}\left(1 - e^{-t\left(\frac{Q}{V_a}\right)}\right) + \frac{Q_u \bullet C_{uo}V_u}{QV_u - Q_uV_a}\left[e^{-t\left(\frac{Q_u}{V_u}\right)} - e^{-t\left(\frac{Q}{V_a}\right)}\right] \qquad (A.5)$$

where,

C_o: Initial concentration inside the modeling volume [Mass/Vol].

Reference

Wylie, C.R., and L.C. Barrett, 1982, Advanced Engineering Mathematics, 5th Ed., PP 1103, McGraw-Hill Co., NY.

APPENDIX B

Nitrate Data

Nitrate Sampling Results from Monitoring Wells

WELL #	500	501	502	502	503	504	504	505	506	506	507	507	508	508	509	509	510	510	511	511	512	513
DEPTH	12	50	16	38	40	62	49	40	15	40	111	70	31	71	61	105	42	57	33	52	44	40
FEB92	12.90	14.50	8.30	6.00	10.80	11.40	5.50	10.20	14.90	9.70	1.50	10.70	4.70	11.80	7.60	12.60	1.60	13.00	15.00	12.60	10.70	3.30
MAR92	15.10	14.30	8.90	6.10	9.30	11.80	8.80	2.10	15.10	10.20	2.70	12.10	7.70	12.60	17.70	12.80	4.20	13.10	15.80	12.80	11.10	2.50
APR92	13.70	13.60	8.60	5.90	8.30	10.10	5.80	0.80	14.00	7.30	1.40	10.30	5.60	11.40	18.00	12.30	2.90	12.30	14.30	12.10	10.50	1.10
MAY92	11.60	13.50	8.90	5.80	8.50	10.00	5.60	1.00	13.70	6.90	1.40	10.20	6.60	11.20	19.50	11.80	4.10	12.10	14.40		10.20	
JUN92	23.00	15.40	11.00	6.85	10.90	12.40	5.96	0.96	15.60	8.79	1.77	12.20	8.00	13.20	22.40	13.80	3.03	14.30	17.60	13.90	12.40	0.25
JUL92	15.00	13.20	9.40	5.90	9.10	10.60	5.20	1.20	13.80	8.40	1.20	10.20	6.40	11.40	20.40	11.50	3.30	12.00	14.20	11.80	9.50	0.80
AUG92	12.80	13.30	9.40	5.80	8.90	10.90	5.40	0.80	13.40	7.90	1.30	10.10	6.30	11.20	19.80	11.40	3.90	12.10	15.00	11.70	9.70	1.30
SEP92	12.30	13.50	9.60	4.50	8.60	11.70	5.50	0.80	13.70	7.80	1.40	10.40	6.60	11.30	21.00	11.60	4.00	12.30	14.90	11.00	10.20	3.00
OCT92	14.20	13.40	10.00	6.20	8.70	10.60	5.00	0.70	12.90	7.40	1.40	10.40	4.70	11.90	20.10	11.90	4.60	11.80	14.60	11.40	10.40	2.20
NOV92	15.30	13.70	10.10	6.30	9.20	11.10	5.80	0.80	13.60	7.80	1.40	9.60	5.90	12.20	20.30	11.90	5.30	12.20	15.40	11.60	10.40	2.80
DEC92	16.20	12.60	9.20	5.40	8.40	10.00	5.30	0.80	14.30	8.10	1.20	9.70	6.50	12.20	20.80	12.20	5.70	12.00	14.90	11.50	10.50	1.80
JAN93	17.70	13.50	9.80	6.20	7.80	11.30	5.80	0.90	14.30	8.00	1.20	9.80	4.90	10.50	20.90	12.40	5.30	12.00	17.50	13.30	13.40	1.80
FEB93	16.70	14.10	10.30	6.40	8.90	11.60	6.20	0.90	14.50	8.30	1.70	10.60	6.40	12.30	20.70	12.40	5.00	12.60	16.40	11.90	10.60	1.70
MAR93	14.30	14.00	10.10	6.30	9.40	11.50	6.10	0.80	14.40	8.40	1.60	10.30	6.20	12.00	20.20	12.40	4.90	12.10	15.00	11.50	11.50	1.50
APR93	13.00	14.80	8.90	5.40	8.70	11.10	5.30	0.09	12.80	6.30	1.10	9.90	5.30	12.00	19.30	10.20	4.30	11.40	14.10	9.90	11.50	0.80
MAY93	17.40	13.80	9.60	6.60	9.20	11.60	7.60	0.90	15.00	8.10	1.50	10.10	7.60	12.30	19.50	12.10	7.50	11.80	15.00	12.10	11.70	1.30
JUN93	9.76	14.70	10.70	7.89	11.20	12.40	8.35	1.01	16.10	8.96	1.81	11.20	9.21	14.60	20.20	13.10	8.49	13.10	14.80	13.60	12.50	1.05
JUL93	9.20	14.10	9.90	7.10	9.30	11.50	7.70	0.80	15.40	8.60	1.50	10.30	6.60	11.80	19.80	12.40	8.30	11.70	14.00	12.30	11.70	1.10
AUG93	9.10	14.10	9.80	7.20	9.10	10.50	7.30	0.80	14.80	8.10	1.30	10.00	8.10	11.60	18.60	11.30	8.40	11.00	11.90	11.60	10.80	1.30
SEP93	11.60	13.70	9.50	7.00	8.80	11.40	6.50	0.80	14.10	7.90	1.30	9.30	7.40	12.50	18.00	11.90	9.50	11.60	11.10	12.10	11.40	2.00
OCT93	13.90	14.00	9.00	6.50	8.70	11.20	6.40	0.60	14.60	7.60	1.30	8.60	5.60	11.60	17.80	11.40	9.50	11.20	9.70	11.70	10.80	1.50
NOV93	15.70	13.60	9.10	6.60	8.80	11.30	6.50	0.50	15.40	8.20	1.20	9.00	4.80	11.60	18.90	11.20	9.90	11.10	8.60	11.70	10.30	1.50
DEC93	16.10	14.20	9.30	7.00	8.60	11.20	5.00	0.50	15.00	8.00	0.90	8.80	3.50	11.70	19.80	12.20	9.40	10.80	7.90	11.90	11.10	0.90

Nitrate Sampling Results from Monitoring Wells

WELL #	514	514	515	516	517	518	518	519	519	520	520	521	521	522	522	523	524	525	526	527	527
DEPTH	36	60	20	24	60	34	63	60	95	45	78	30	57	26	44	14	38	25	35	30	50
FEB92	15.00	5.50	1.40	18.60	3.60	10.40	3.30	13.50	2.50	15.20	5.00	0.09	0.09	0.09	0.09	2.80	10.00	12.60	6.80	9.70	0.09
MAR92	15.30	6.10	1.60	20.60	4.60	10.60	3.70	13.50	2.70	15.00	5.30	0.09	0.09	0.09	0.09	2.80	10.20	12.90	10.00	9.90	0.50
APR92	14.20	7.60	1.90	20.70	3.40	10.20	3.30	12.30	2.40	14.30	4.80	0.09	0.09	0.09	0.09	3.00	9.70	12.00	10.20	9.40	0.40
MAY92	14.30	9.60	1.80	22.10	3.50	10.40	3.40	12.40	2.60	13.80	5.00	0.09	0.00	0.09	0.09	2.10	9.80	11.90	12.50	9.70	0.40
JUN92	16.50	11.70	2.17	21.20	3.85	11.90	3.91	13.40	3.05	15.80	5.61	0.01	0.01	0.25	0.01	2.43	11.00	14.40	13.80	10.40	0.58
JUL92	14.30	12.30	1.80	18.70	3.60	9.90	3.30	12.10	2.60	14.50	5.00	0.09	0.09	0.09	0.09	2.20	9.50	11.30	12.60	9.30	0.40
AUG92	14.10	10.60	1.60	19.00	3.40	10.10	3.40	11.60	2.30	14.40	4.80	0.09	0.09	0.09	0.09	2.00	9.60	10.80	11.90	9.30	0.09
SEP92	15.30	11.50	1.40	19.80	3.30	8.50	2.60	14.10	2.00	15.10	4.10	0.09	0.09	0.09	0.09	1.90	9.70	11.80	12.70	7.40	0.09
OCT92	14.00	10.60	1.40	19.20	3.80	10.00	3.30	11.80	2.50	14.30	5.00	0.09	0.09	0.09	0.09	1.60	9.80	11.00	10.80	9.50	0.09
NOV92	13.70	10.60	1.30	18.90	3.90	10.00	3.20	13.00	2.50	15.10	5.50	0.09	0.09	0.09	0.09	1.40	9.80	10.90	11.30	9.90	0.09
DEC92	14.20	11.90	1.40	17.70	3.90	10.50	3.50	12.40	2.70	14.50	5.40	0.09	0.09	0.09	0.09	1.50	10.10	11.30	11.30	9.50	0.40
JAN93	15.00	15.10	1.80	18.60	3.00	9.60	3.00	11.20	2.40	13.70	4.90	0.09	0.09	0.09	0.09	1.30	9.80	10.50	10.10	8.60	0.09
FEB93	15.90	16.50	1.70	18.40	3.80	10.60	3.50	12.90	2.70	15.10	5.40	0.09	0.09	0.09	0.09	1.70	10.20	11.00	9.20	9.90	0.40
MAR93	15.90	15.90	1.50	18.40	3.80	10.30	3.30	12.20	2.30	15.30	4.90	0.09	0.09	0.09	0.09	1.90	10.10	10.70	9.20	9.80	0.09
APR93	14.20	15.90	1.30	17.70	3.30	9.90	2.70	11.60	2.30	15.50	4.40	0.09	0.09	0.09	0.09	2.20	9.30	9.80	8.40	9.60	0.09
MAY93	14.40	15.40	1.40	16.80	3.80	10.00	3.60	12.10	2.70	16.00	5.40	0.09	0.09	0.60	0.09	3.50	10.10	9.80	9.40	9.40	0.40
JUN93	17.20	14.90	1.77	17.40	4.68	10.84	3.98	12.80	3.07	18.40	6.42	0.05	0.03	0.66	0.07	4.29	10.50	10.90	11.80	10.50	0.54
JUL93	15.40	13.10	1.40	17.50	4.20	10.10	3.60	12.70	2.50	16.20	5.40	0.09	0.09	0.70	0.09	4.10	10.10	9.70	11.60	9.30	0.40
AUG93	15.10	13.70	1.30	17.30	4.80	12.70	3.80	12.30	3.00	16.20	5.80	0.09	0.09	0.70	0.09	3.90	10.30	8.60	11.30	9.10	0.50
SEP93	14.80	12.90	1.20	16.50	4.20	9.60	3.30	12.10	2.50	14.90	5.30	0.09	0.10	0.40	0.09	3.40	9.90	8.50	11.60	8.80	0.30
OCT93	14.20	12.20	1.20	16.60	4.00	9.40	3.20	11.00	2.20	13.60	4.70	0.09	0.09	0.09	0.09	2.80	9.60	6.90	10.40	8.00	0.09
NOV93	14.10	12.20	1.10	15.90	3.70	9.10	3.00	11.60	2.10	13.90	5.00	0.09	0.09	0.09	0.09	2.30	11.40	5.90	10.20	8.50	0.09
DEC93	14.10	12.10	1.00	15.90	2.90	7.20	2.50	11.60	1.70	13.70	4.80	0.09	0.09	0.09	0.09	2.40	11.70	5.60	9.90	6.70	0.09

APPENDIX C

Modeling Output

Pretty Prairie Nitrate Stuydy (study area = 4x7 miles) File Name: KAN4.XLS

Mar. 24, 1994 Sam Lee

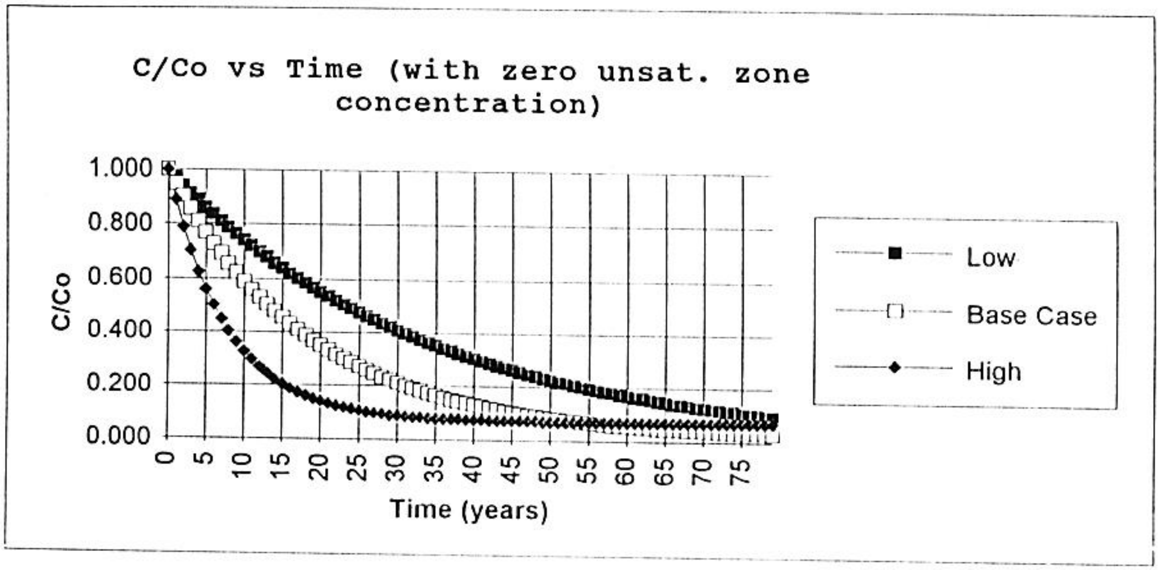
						LOW	BASE	HIGH
K=		4.60E-05	m/s	13.0400064	ft/d	1.30400064	13.04	130.400064
i1=		11.11111	50ft/4.5mile	0.00210438	ft/ft	0.00210438	0.00210438	0.00210438
i2=		6.25	125ft/20mile	0.00118371	ft/ft			
n=				0.3	vol/vol	0.3	0.3	0.3
Area1	Plan Ar=			780595200	ft^2	780595200	780595200✓	780595200
	7 Lehgth	7 mile		36960	ft			
	4 Width	4 mile		21120	ft	21,120	21,120	21,120
	Thk	50 ft		30	ft	40	30	20
	X- Ar=			633600	ft^2	844,800	633,600 √	422,400
Sat Volume	Va			7025356800	ft^3	9367142400	7025356800	4683571200
Annual av rainfall (28.61 in/yr) at Witchita,KS								
Infiltration		28.61	in/yr	0.00130639	ft/d	15%	20%	30%
Aguifer Flow		Qa1=		17,387	ft^3/d	2,318	17,387	115,911
		Qa2 =		9,780	ft^3/d			
Recharge Flow		Qr = Qu=		1,019,764	ft^3/d	764,823	1,019,764	1,529,646
Total Flow (Q)		Qa1+Qr =		1,037,151	ft^3/d	767,141	1,037,151	1,645,557
		Qa2+Qr =		1,029,544	ft^3/d			
Init Conc Co		20	mg/L			20	20	20
Aquif Conc Ca		20	mg/L			20	20	20
Rech Conc 1		0	mg/L (1)			0	0	0
Rech Cuo		20	mg/L (2)			20	20	20
Qa*Ca/Q						0.06043799	0.33527775	1.40877734
Qr*Cr(1)/Q						0	0	0
Q/Va						8.1897E-05	0.00014763	0.00035135
Unsat Thk		20	ft	20	ft	20	20	20
Unsat n(water filled)					vol/vol	0.15	0.15	0.15
Unsat Vol (Vu)	Vu				ft^3	2341785600	2341785600	2341785600
Qu/Vu	Qu/Vu					0.0003266	0.00043546	0.0006532
Qu*Cuo*Vu/(Q*Vu-Qu*Va)						-6.67340917	-10.0859815	-21.6397868

C/Co vs Time (with zero unsat zone conc.)

Time (t)	Yr	Low	Base Case	High
0	0	1.000	1.000	1.000
365	1	0.971	0.948	0.888
730	2	0.942	0.900	0.790
1095	3	0.914	0.853	0.703
1460	4	0.888	0.809	0.627
1825	5	0.862	0.768	0.560
2190	6	0.836	0.728	0.501
2555	7	0.812	0.691	0.449
2920	8	0.788	0.656	0.404
3285	9	0.765	0.622	0.364
3650	10	0.742	0.590	0.328
4015	11	0.721	0.560	0.297
4380	12	0.699	0.532	0.270
4745	13	0.679	0.505	0.246
5110	14	0.659	0.479	0.225
5475	15	0.640	0.455	0.206
5840	16	0.621	0.432	0.190
6205	17	0.603	0.410	0.176
6570	18	0.585	0.390	0.163
6935	19	0.568	0.370	0.152
7300	20	0.551	0.351	0.142
7665	21	0.535	0.334	0.133

8030	22	0.520	0.317	0.126
8395	23	0.504	0.301	0.119
8760	24	0.490	0.287	0.113
9125	25	0.475	0.272	0.108
9490	26	0.461	0.259	0.104
9855	27	0.448	0.246	0.100
10220	28	0.435	0.234	0.096
10585	29	0.422	0.223	0.093
10950	30	0.410	0.212	0.090
11315	31	0.398	0.202	0.088
11680	32	0.386	0.192	0.086
12045	33	0.375	0.183	0.084
12410	34	0.364	0.174	0.082
12775	35	0.353	0.166	0.081
13140	36	0.343	0.158	0.080
13505	37	0.333	0.151	0.079
13870	38	0.323	0.144	0.078
14235	39	0.314	0.137	0.077
14600	40	0.305	0.131	0.076
14965	41	0.296	0.125	0.075
15330	42	0.287	0.119	0.075
15695	43	0.279	0.114	0.074
16060	44	0.271	0.109	0.074
16425	45	0.263	0.104	0.073
16790	46	0.255	0.099	0.073
17155	47	0.248	0.095	0.073
17520	48	0.240	0.091	0.072
17885	49	0.233	0.087	0.072
18250	50	0.227	0.083	0.072
18615	51	0.220	0.080	0.072
18980	52	0.214	0.076	0.072
19345	53	0.207	0.073	0.071
19710	54	0.201	0.070	0.071
20075	55	0.196	0.068	0.071
20440	56	0.190	0.065	0.071
20805	57	0.184	0.062	0.071
21170	58	0.179	0.060	0.071
21535	59	0.174	0.058	0.071
1900	60	0.169	0.056	0.071
22265	61	0.164	0.054	0.071
22630	62	0.159	0.052	0.071
22995	63	0.155	0.050	0.071
23360	64	0.150	0.048	0.071
23725	65	0.146	0.046	0.071
24090	66	0.142	0.045	0.071
24455	67	0.138	0.043	0.071
24820	68	0.134	0.042	0.071
25185	69	0.130	0.041	0.071
25550	70	0.126	0.039	0.071
25915	71	0.122	0.038	0.071
26280	72	0.119	0.037	0.071

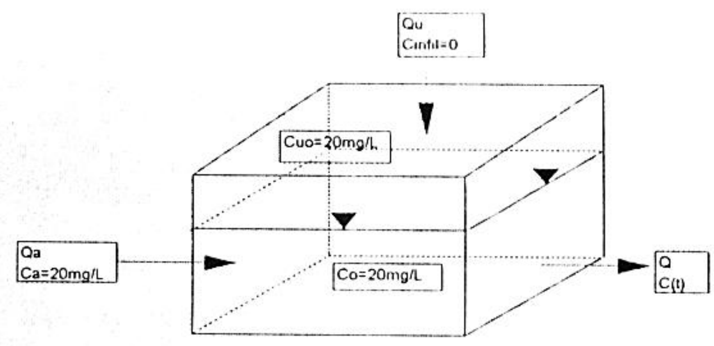
26645	73	0.115	0.036	0.071
27010	74	0.112	0.035	0.071
27375	75	0.109	0.034	0.071
27740	76	0.106	0.033	0.070
28105	77	0.103	0.032	0.070
28470	78	0.100	0.031	0.070
28835	79	0.097	0.031	0.070



Sensitivity Analysis

	K(cm/sec)	Thk(ft)	Infiltration*
High	4.60E-02	20	30%
Base Case	4.60E-03	30	20%
Low	4.60E-04	40	15%

* Infiltration = % of Annual Rainfall @ Wichita, KS



CONTROL VOLUME FOR NITRATE TRANSPORT THROUGH UNSATURATED AND SATURATED ZONE

Conc Reduction at the Unsat Zone

Cr,t, Low	Cr,t BASE	Cr,t HIGH
20.000	20.000	20.000
17.752	17.061	15.757
15.757	14.554	12.415
13.987	12.415	9.781
12.415	10.590	7.707
11.020	9.034	6.072
9.781	7.707	4.784
8.682	6.574	3.769
7.707	5.608	2.970
6.840	4.784	2.340
6.072	4.081	1.843
5.389	3.481	1.452
4.784	2.970	1.144
4.246	2.533	0.902
3.769	2.161	0.710
3.345	1.843	0.560
2.970	1.572	0.441
2.636	1.341	0.347
2.340	1.144	0.274
2.077	0.976	0.216
1.843	0.833	0.170
1.636	0.710	0.134

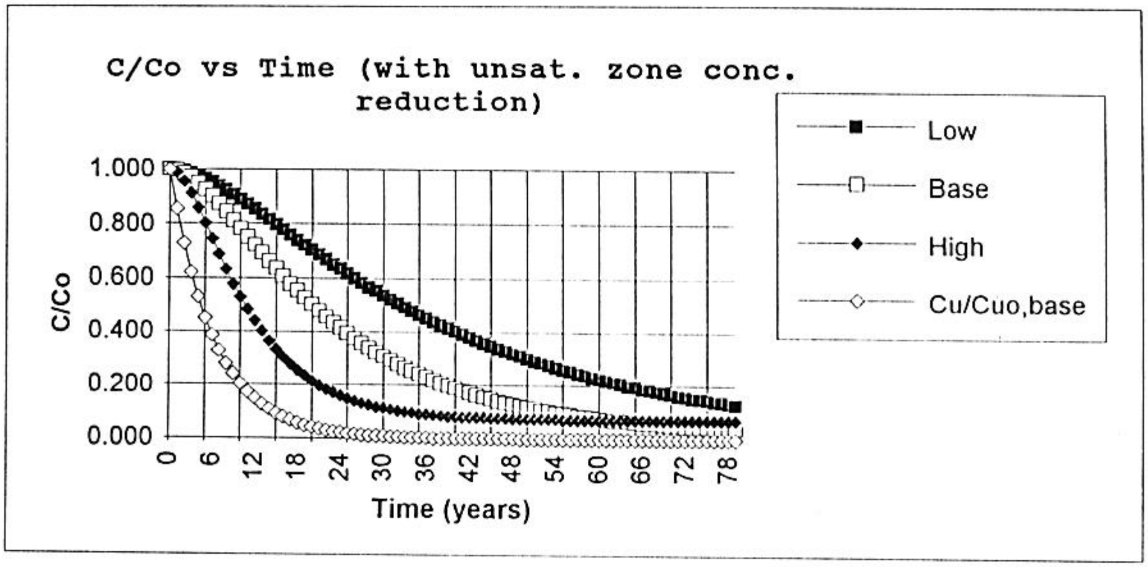
C/Co vs Time (with unsat zone conc. reduction)

Yr	Low	Base	High	Cu/Cuo,base
0	1.000	1.000	1.000	1.000
1	0.998	0.996	0.987	0.853
2	0.994	0.985	0.955	0.728
3	0.986	0.969	0.910	0.621
4	0.977	0.949	0.858	0.530
5	0.965	0.925	0.801	0.452
6	0.952	0.899	0.744	0.385
7	0.938	0.871	0.686	0.329
8	0.922	0.842	0.631	0.280
9	0.906	0.812	0.578	0.239
10	0.889	0.782	0.529	0.204
11	0.871	0.751	0.483	0.174
12	0.853	0.721	0.440	0.148
13	0.834	0.691	0.401	0.127
14	0.816	0.662	0.366	0.108
15	0.797	0.633	0.334	0.092
16	0.778	0.605	0.305	0.079
17	0.760	0.578	0.279	0.067
18	0.741	0.552	0.256	0.057
19	0.722	0.527	0.235	0.049
20	0.704	0.502	0.216	0.042
21	0.686	0.479	0.199	0.036

1.452	0.606	0.105
1.289	0.517	0.083
1.144	0.441	0.065
1.016	0.376	0.052
0.902	0.321	0.041
0.800	0.274	0.032
0.710	0.233	0.025
0.630	0.199	0.020
0.560	0.170	0.016
0.497	0.145	0.012
0.441	0.124	0.010
0.391	0.105	0.008
0.347	0.090	0.006
0.308	0.077	0.005
0.274	0.065	0.004
0.243	0.056	0.003
0.216	0.048	0.002
0.191	0.041	0.002
0.170	0.035	0.001
0.151	0.030	0.001
0.134	0.025	0.001
0.119	0.022	0.001
0.105	0.018	0.001
0.094	0.016	0.000
0.083	0.013	0.000
0.074	0.011	0.000
0.065	0.010	0.000
0.058	0.008	0.000
0.052	0.007	0.000
0.046	0.006	0.000
0.041	0.005	0.000
0.036	0.004	0.000
0.032	0.004	0.000
0.028	0.003	0.000
0.025	0.003	0.000
0.022	0.002	0.000
0.020	0.002	0.000
0.018	0.002	0.000
0.016	0.001	0.000
0.014	0.001	0.000
0.012	0.001	0.000
0.011	0.001	0.000
0.010	0.001	0.000
0.009	0.001	0.000
0.008	0.001	0.000
0.007	0.000	0.000
0.006	0.000	0.000
0.005	0.000	0.000
0.005	0.000	0.000
0.004	0.000	0.000
0.004	0.000	0.000

22	0.668	0.456	0.184	0.030
23	0.651	0.434	0.171	0.026
24	0.633	0.414	0.160	0.022
25	0.616	0.394	0.149	0.019
26	0.600	0.375	0.140	0.016
27	0.583	0.357	0.132	0.014
28	0.567	0.340	0.125	0.012
29	0.552	0.323	0.118	0.010
30	0.536	0.308	0.113	0.008
31	0.522	0.293	0.108	0.007
32	0.507	0.279	0.103	0.006
33	0.493	0.265	0.099	0.005
34	0.479	0.253	0.096	0.004
35	0.465	0.240	0.093	0.004
36	0.452	0.229	0.090	0.003
37	0.439	0.218	0.088	0.003
38	0.427	0.208	0.086	0.002
39	0.415	0.198	0.084	0.002
40	0.403	0.188	0.082	0.002
41	0.391	0.179	0.081	0.001
42	0.380	0.171	0.080	0.001
43	0.369	0.163	0.079	0.001
44	0.358	0.155	0.078	0.001
45	0.348	0.148	0.077	0.001
46	0.338	0.141	0.076	0.001
47	0.328	0.135	0.075	0.001
48	0.319	0.129	0.075	0.000
49	0.310	0.123	0.074	0.000
50	0.301	0.117	0.074	0.000
51	0.292	0.112	0.073	0.000
52	0.284	0.107	0.073	0.000
53	0.275	0.102	0.073	0.000
54	0.267	0.098	0.072	0.000
55	0.260	0.093	0.072	0.000
56	0.252	0.089	0.072	0.000
57	0.245	0.086	0.072	0.000
58	0.238	0.082	0.072	0.000
59	0.231	0.079	0.071	0.000
60	0.224	0.075	0.071	0.000
61	0.218	0.072	0.071	0.000
62	0.211	0.069	0.071	0.000
63	0.205	0.067	0.071	0.000
64	0.199	0.064	0.071	0.000
65	0.194	0.062	0.071	0.000
66	0.188	0.059	0.071	0.000
67	0.182	0.057	0.071	0.000
68	0.177	0.055	0.071	0.000
69	0.172	0.053	0.071	0.000
70	0.167	0.051	0.071	0.000
71	0.162	0.049	0.071	0.000
72	0.158	0.047	0.071	0.000

0.003	0.000	0.000	73	0.153	0.046	0.071	0.000
0.003	0.000	0.000	74	0.149	0.044	0.071	0.000
0.003	0.000	0.000	75	0.144	0.043	0.071	0.000
0.002	0.000	0.000	76	0.140	0.042	0.071	0.000
0.002	0.000	0.000	77	0.136	0.040	0.071	0.000
0.002	0.000	0.000	78	0.132	0.039	0.071	0.000
0.002	0.000	0.000	79	0.128	0.038	0.071	0.000



Sensitivity Analysis

	K(cm/sec)	Thk(ft)	Infiltration*
High	4.60E-02	20	30%
Base Case	4.60E-03	30	20%
Low	4.60E-04	40	15%

* Infiltration = % of Annual Rainfall @ Wichita, KS